THERMAL STRESS EFFECT ON DISC BRAKE ROTOR FOR NGV VEHICLE

BAHROM BIN BAHARIN

MASTER OF MECHANICAL ENGINEERING (ENERGY ENGINEERING)

2017

FACULTY OF MECHANICAL ENGINEERING

THERMAL STRESS EFFECT ON DISC BRAKE ROTOR FOR NGV VEHICLE

BAHROM BIN BAHARIN

MASTER OF MECHANICAL ENGINEERING (ENERGY ENGINEERING)

2017

THERMAL STRESS EFFECT ON DISC BRAKE ROTOR FOR NGV VEHICLE

BAHROM BIN BAHARIN

A report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the award of Master of Mechanical Engineering (Energy Engineering)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality as a partial fulfillment of Master of Mechanical Engineering (Energy Engineering).

Signature	:………………………………………………
Supervisor Name	:………………………………………………
Date	:………………………………………………

DECLARATION

I declare that this report entitled "Thermal Stress Effect On Disc Brake Rotor For NGV Vehicle" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	....
Date	:	....

ABSTRACT

Braking system is one of the safety aspects in vehicle design that is very important to stop a vehicle safely and avoiding an imminent collision with another vehicle, person or obstacle. During braking operation, most of the kinetic energy is converted into thermal energy and thus increases the disc temperature. Excessive temperature with poor heat dissipation would causes problems such as cracking, coning and brake pad failure. Therefore it is important to have sound knowledge on temperature distribution and thermal stress so that the designed brake will fully function. This study was conducted with a focus on the effect of thermal stress and temperature distribution behaviour on ventilated disc brake with various loading of the NGV vehicle. Steady state and transient response are used to predict the temperature distribution, deformation as well as stresses during the worst and extreme braking condition. Finite element analysis approached is conducted to identify the temperature distributions and behaviours of disc brake rotor in steady state and transient response. ANSYS software is used to perform the thermal analysis and predict the temperature distributions and behaviours at various loads. Results from both steady state and transient response are compared so that the result will assist the automotive industry in developing optimum and effective disc brake rotor.

ABSTRAK

Sistem brek merupakan salah satu daripada aspek keselamatan dalam reka bentuk kenderaan yang sangat penting untuk menghentikan kenderaan dengan selamat dan mengelakkan dari berlakunya perlanggaran dengan kenderaan lain, orang atau halangan. Semasa operasi membrek, kebanyakan tenaga kinetik ditukar kepada tenaga haba dan dengan itu meningkatkan suhu cakera. Suhu yang berlebihan dengan pelesapan haba yang lemah akan menyebabkan masalah seperti keretakan, perubahan bentuk kepada kon dan kegagalan pad brek. Oleh itu adalah penting untuk mempunyai pengetahuan luas tentang taburan suhu dan tegasan haba supaya brek yang direka dapat berfungsi sepenuhnya. Kajian ini dijalankan dengan memberi tumpuan kepada kesan tingkah laku tekanan dan taburan suhu haba ke atas cakera brek berongga dengan pelbagai bebanan terhadap kenderaan jenis NGV. Tindakbalas keadaan mantap dan keadaan berubah dengan masa digunakan untuk meramal taburan suhu, perubahan bentuk dan juga tegasan semasa keadaan membrek yang paling teruk dan melampau. Langkah analisis unsur terhingga dijalankan untuk mengenal pasti taburan suhu dan tingkah laku cakera brek dalam tindakbalas keadaan mantap dan keadaan berubah dengan masa. Perisian ANSYS digunakan untuk melaksanakan analisis terma dan meramalkan taburan suhu dan tingkah laku pada pelbagai beban. Keputusan daripada kedua-dua tindakbalas keadaan mantap dan keadaan berubah dengan masa dibandingkan supaya hasilnya akan membantu industri automotif dalam membangunkan cakera brek yang optimum dan berkesan.

ACKNOWLEDGEMENTS

First of all I would like to say Alhamdulillah and thank to the God for the blessing given that allow me to be able to complete the report successfully within the required duration. Secondly I would first like to thank my supervisor Dr Mohd Zaid Akop of the Faculty of Mechanical Engineering, Universiti Teknikal Malaysia (UTeM) Melaka. The door to his office was always open whenever I ran into a trouble spot or had a question about my research or writing. He consistently allowed this paper to be my own work, but steered me in the right the direction whenever he thought I needed it.

Besides, I would also like to acknowledge Dr Abdul Rahim Abu Bakar from Universiti Teknologi Malaysia for sharing valuable knowledge regarding thermal stress and finite element analysis of disc brake rotor. I am gratefully indebted for his very valuable comments on this thesis. I would also like to thank Mr. Phillip Joseph, Managing Director of Disc Brakes Australia and the staff of Wilwood Disc Brake for cooperation regarding disc brake design. Big thanks and appreciations to Mr. Ahmad Nazrin Bin Ali @Yusof, who helps me in doing ANSYS simulation and also to Mr. Asjufri Bin Muhajir, technician from Air Conditioning and Thermodinamik Lab UTeM who helps me in using and lending infrared thermal imaging camera. Without their passionate participation and input, this thesis could not have been successfully conducted. Furthermore, I would like thank my employer, Cawangan Kejuruteraan Mekanikal, Jabatan Kerja Raya Malaysia for giving me the opportunities and chances to further my study in Energy Engineering.

Finally, I must express my very profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

$\dot{q}$	–	Heat Flux (W/m^2)
$\dot{Q}$	–	Heat Transferred per Unit Time is (J/s or Watt, W)
Q	–	Thermal Energy (Joule, J)
ΔT	–	Average temperature increase per stop (°C)
$\dot{Q}_{cond}$	–	Conduction Heat Transfer (kW)
$\dot{Q}_{conv}$	–	Convection Heat Transfer (kW)
$\dot{Q}_{emit}$	–	Radiation Heat Transfer (kW)
(Al-MMC)	–	Aluminium Metal Matrix Composite
(CH4)	–	Methane
(DBA)	–	Disc Brake Australia
$[C]$	–	Thermal capacitance matrix
$[K]$	–	Stiffness Matrix
$\{\dot{T}\}$	–	Vector of nodal rates of temperature increases
$\{F\}$	–	Nodal Forces
$\{T\}$	–	Thermal Condition Containing Temperature
$\{\delta\}$	–	Resultant Nodal Displacement
μ	–	Dynamic Viscosity of air (1.872 x 10^{-5} kg/m.s)
μ_p	–	Friction coefficient of brake pad and disc surface
μ_R	–	Coefficient of friction of dry tarmac, gritted bitumen
A	–	Area (m^2)
A_{sect}	–	Cross sectional area normal to the direction of heat transfer (m^2).
A_p	–	Pad area (m^2)
A_{bs}	–	Area of both sides (m^2)
A_R	–	Rotor surface area (m^2)

$Area_{in}$	–	Inner radius area of disc brake
$Area_{out}$	–	Outer radius area or disc brake
A_s	–	Surface area of object (m^2)
A_s	–	Surface area through which convection heat transfer occurs (m^2)
BCIRA	–	British Cast Iron Research Association
CAD	–	Computer Aided Design
CFD	–	Computational Fluid Dynamic
CG	–	Centre Gravity (mm)
CGH	–	Centre Gravity Height (mm)
CMM	–	Coordinate Measuring Machine
CNG	–	Compressed Natural Gas
C_p	–	Specific heat capacity, (J/kg.K)
c_R	–	Specific heat grey cast iron (J/kg.°C)
d_h	–	Hydraulic diameter (m)
D_i	–	Inner diameter (m)
D_o	–	Outer diameter (m)
DR	–	Deceleration of normal passenger
E	–	Young's modulus, (Gpa)
ε	–	Emissivity ($0 \leq \varepsilon \leq 1$)
F	–	Force on each pad (N)
F_{BF}	–	Braking force at front tyre
F_{BR}	–	Brake force from pad friction (N)
FEA	–	Finite element analysis
FEM	–	Finite Element Method
FKM	–	Fakulti Kejuruteraan Mekanikal
GW	–	Gross Weight
h	–	Convection Heat Transfer Coefficient, in $W/m^2.K$
h_c	–	Convection heat transfer coefficient of disc brake (W/m^2K)
h_R	–	Heat transfer coefficient of rotor surface (W/m^2K)
IGES	–	Initial Graphics Exchange Specification
k	–	Thermal conductivity, (W/m°C)
k	–	Thermal Conductivity, watt per meter per Kelvin (W/mK).
k_a	–	Thermal conductivity of air (W/m.K)
L	–	Vane length (m)

L	–	Length (mm)
L	–	Wheelbase of the car
LNG	–	Liquefied Natural Gas
m_c	–	Gross mass of vehicle
$\mathrm{M_F}$	–	Moment of equilibrium
m_R	–	Mass of rotor (kg)
N_{disc}	–	Angular velocity of the tyre (rpm)
NGV	–	Natural Gas Vehicle
NU_D	–	Nusselt Number of disc brake
p	–	Pressure (Pa)
P_{ave}	–	Average pad pressure applied on disc surface (MPa)
A_p	–	Brake pad area (m^2)
$\mathrm{P_B}$	–	Braking Power (W)
Pr	–	Prandtl number
$q_{inboard}$	–	Heat flux generated on the inboard surfaces (W/m^2)
$q_{outboard}$	–	Heat flux generated on the outboard surfaces (W/m^2)
r	–	Mean radius (from centre wheel to centre pad) (m)
r_0	–	Outer radius of disc (m)
R_{ave}	–	Radius of average vane ring (m)
r_c	–	Radius of disc centroid/mean radius from centre wheel to centre pad (m)
Re	–	Reynolds number of disc braking surface
$\mathrm{R_F}$	–	Reaction force at front
R_F	–	Force reaction on front tyres
$\mathrm{R_R}$	–	Reaction force at rear
r_t	–	Radius of tyre
r_{tyre}	–	Radius of 185/60R14tyre (mm)
r_{tyre}	–	Radius of tyre (288.29 mm, Size of tyre :185/60R14)
R_{vi}	–	Radius of vane inner ring (m)
R_{vo}	–	Radius of vane outer ring (m)
S_{ave}	–	Average ring chord length (m)
SG	–	Ductile iron
S_{in}	–	Inner ring chord length (m)
S_{out}	–	Outer ring chord length (m)

S_{total}	–	Total Distance
T	–	Braking torque (Nm)
T	–	Temperature difference between two surfaces separated by distance Δx (K/°C)
T_{∞}	–	Ambient temperature (°C)
T_{∞}	–	Ambient temperature (K/°C)
$T_{braking}$	–	Brake torque
t_C	–	Cooling time cycle (s)
Ts	–	Braking Time
t_S	–	Brake time (6s)
T_s	–	Surface temperature (K/°C)
T_s	–	Surface temperature of object (K/°C)
T_{tyre}	–	Tyre torque
UK	–	United Kingdom
$\mathrm{V_{air\text{-}ave}}$	–	Average air velocity (m/s)
$\mathrm{V_{air\text{-}in}}$	–	Velocity of air flow through the inlet of inner vane passage (m/s)
$\mathrm{V_{air\text{-}out}}$	–	Velocity of air flow through the outlet of inner vane passage (m/s)
v_R	–	Rotor volume (m^3)
Vtr	–	Travel Speed
$V_{vehicle}$	–	Velocity of normal passenger (m/s)
WB	–	Wheelbase (mm)
$\mathrm{Weight_R}$	–	Weight distribution of vehicle at rear axle
WT	–	Weight transfer
WT_{Front}	–	Weight transfer at front tyre
W_{total}	–	Total weight of car
Δh	–	Height of rear axle when rise
ΔW_f	–	Front tyre weight reading on scale during test
Δx	–	Wall Thickness (m)
θ	–	Fraction angle (°)
μ	–	Coefficient of friction
ν_a	–	Kinematic viscosity of air (m^2/s)
ρ	–	Density, (kg/m^3)
ρ_R	–	Rotor density (kg/m^3)
σ	–	Stefan-Boltzman constant (5.670×10^{-8} $W/m^2.K^4$)

ω_{disc}	–	Angular velocity of the disc (rad^{-1})
ω_{tyre}	–	Angular velocity of the tyre (rad^{-1})